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STUDY OF ARCUATE STRUCTURAL TRENDS IN UTAH AND NEVADA USING ERTS-1 IMAGERY

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16. Abstract

Patterns of linear trends traced from ERTS-1 imagery in Utah and Nevada suggest that there is a network of interrelated regional structural trends. These trends occur in parallel sets and appear to mutually offset each other at intersections with sets of another orientation. The intersections may be intrusive centers or show other crustal disturbance. Mutual offsetting of trends in the same relative direction of movement causes tension which may produce basins and create conduits for basic igneous activity; offsetting in the opposite relative direction causes compression, crushing, thrusting, and possibly melting of deep siliceous crust. It may also cause rotation of the blocks of crust at the intersection, and tilting of the blocks if the controlling faults are not vertical. Stress release along latitudes of rotation around the compressive centers may explain arcuate trends which are circular segments, may occur in concentric sets, and may be geologic as well as geomorphic and structural boundaries. They occur in complex overlapping relationships and may control Basin-Range structures.

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Preface

This study of the gross structural relationships in the Basin-Range Province of Utah and Nevada is based on the assumption that geomorphic structures visible on ERTS-1 imagery are controlled by tectonic deformation and should therefore expose regular patterns of that deformation, if any exist, especially in an area of the size studied.

Linear structural trends other than man-made were traced from a 1:1,000,000 scale mosaic made from ERTS-1 imagery. Separation into limited orientation-sets indicates that some trends occur in parallel sets and may be traced for considerable distances but may be mutually offset where they intersect trends of another orientation. Some trend alignments show a regular change of orientation, with the trend segments tangential to a regular curve. The possible interpretation of these arcuate trends was chosen for this study.

The arcuate trends occur in complex overlapping relationships in all sizes from a few hundred meters to over a thousand kilometers in diameter. They may be geologic and structural as well as geomorphic boundaries. They may be separated into single concentric sets about a common center. The geometric centers appear to be the mutually offset regional trends described above. The arcuate trends appear to be traces of movement of blocks of crust rotating about the centers in response to movement along major faults.

Further work recommended includes aeromagnetic traverses to find if major arcuate trends can be traced and mapped by geophysical techniques; research on the mechanics of an incompetent crust floating on a mobile layer; application of techniques suggested (separation of single sets of arcuate structures) as a mapping tool for structural geology, and extension of the study to the entire western United States to look for major patterns and their relationship to the tectonic history of the region.

Conclusions

1. Regional trend patterns as traced from ERTS-1 imagery of Utah and Nevada indicate an overall network of basic structures which may be deep fractures; movement along these fractures controls local structures.

2. Where regional trends of a number of orientations intersect, there is often apparent mutual offsetting of the intersecting structures. These intersections may be loci of intrusive centers or other crustal disturbance. Reactivation of faults is suggested by the mutual offsetting and the effect of this reactivation may be compressional or tensive.

3. Structures traceable on ERTS-1 imagery as circular segments (arcuate trends) may be traces of movement of blocks of crust which have rotated in response to movement along the regional trends, with axes of rotation at mutually offsetting intersections of several orientations of regional trends. The arcuate trends range in diameter from a few hundred meters to more than 1000 km. They may occur in concentric sets and very complex overlapping relationships as a result of movement around a number of adjacent centers.

4. Separation of arcuate trends into individual sets may provide useful tools for structural analysis. The arcuate trend curvature points to the center of disturbance, which may be an intrusive or mineralized center; careful tracing of concentric sets individual sets having single centers with careful attention to offsetting and terminations should help in determining relative age and direction of movement.

Recommendations

1. The actual existance of the arcuate trends as traces of block movement should be checked by a number of aeromagnetic traverses across selected trends, by comparison with mapped geology, and by careful joint and fracture analysis.

2. A single "center" should be carefully mapped to look for the relationships suggested by the patterns on the ERTS-1 imagery, using ERTS-1 imagery for gross control, and AMS and regular air photography for detailed mapping.

3. Research needs to be done (or, if it has been done, the results considered) on the mechanical properties of an incompetent crust floating on a plastic mobile base, to see if the principles suggested in this report would be applicable to the very large crustal fragments involved as well as small local structures, and to relate this to the present understanding of plate tectonics.

4. Extension of this study might be made of the entire western United States, to look for major regional and arcuate trend patterns, for time and space relationships between major igneous centers (known and indicated by the ERTS-1 structures), and for major structural relationships which could have some bearing on the tectonic history of the western United States including possible movement of plate segments and the effects of interaction between these moving segments.

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(This report contains part of the material prepared for a Doctoral dissertation at the University of Utah, under the chairmanship of Dr. M. L. Jensen, Principal Investigator on ERTS-1 Contract No. NAS5-21883, whom I wish to thank for making the ERTS-1 imagery and a part-time research assistantship available through NASA funds.)

INTRODUCTION

ERTS-1 imagery has been used to study structural relationships in a part of the Basin-Range province in Utah and Nevada. It is a basic assumption that the geomorphology and topography reflect the gross structural features of the region. Rock that is jointed or fractured as a result of structural deformation is more readily weathered and eroded by running water, frost, or wind, and if there is any regular pattern to the structural deformation, that pattern should be made evident by the erosion. Many authors, among them Rich, E. L. (1973), p. 395-402; Goetz, A. F. H., et al. (1973)p. 404-405; Rowan, L. C. and Wetlaufer, P. H. (1973), p. 413-417, etc., have discussed the clarity with which linear structures unnoticed on the ground can be discerned by ERTS-1 imagery. Field correlation has shown that many of the structures are extensions of known faults; some are faults as yet unmapped, while others are not easily checked because they are covered or diffused. It is interesting that on the scale of the ERTS-1 imagery, rock type appears to have very little influence on the structure patterns. An intensive study has been made of the interrelationships of the linear structures including arcuate patterns which appear to be intimately related to Basin-Range structures. This space imagery study has led to a possible new interpretation of the gross geologic structural relationships in Utah or Nevada.

STRUCTURAL TRENDS

Those linear features visible on the ERTS-1 imagery which are straight, greater than a kilometer in length and not man-made are here called "structural trends" to avoid any genetic meaning. The linear geomorphic features selected as structural trends may be:

1. Geomorphic boundaries
2. Fault scarps
3. Strike valleys
4. Drainage patterns

5. Boundaries between areas having different structural orientations.
6. Grain (small parallel lineations up to a few kilometers in length, probably controlled by rock jointing as described by Kelley and Clinton (1960).
7. Boundaries of textural or color change, reflecting rock type, soil, vegetation, or depositional patterns.

REGIONAL TRENDS

Structural trends may be found in every possible orientation. To trace all of them is impossible; the result is a fine net-work pattern which gives the impression that the crust in the Basin-Range province is broken in a mosaic of small, angular blocks of a size limited by the resolution of the imagery. Sets of limited orientation have been traced to study the distribution of the trends; some trends appear to be continuous with only small breaks or offsets for hundreds of kilometers. These continuities are here called "regional trends."

Selected regional trends traced from the 1:1,000,000 scale ERTS-1 photo mosaic of Utah and Nevada show an overall pattern of intersecting parallel sets of trends as shown on Figure I. Some east-west trends may be followed across the two states with little change in orientation for a distance of nearly 2,000 kilometers. The selection of these trends is somewhat arbitrary, showing only representatives of many possible parallel sets. Those trends are selected which appear to be the most continuous, which form prominant geomorphic boundaries, and which show up as obvious lineations. Any single orientation may follow a range boundary for a few tens of kilometers, then cross the range and adjacent basins. Some continuities show a slight but regular change in orientation.

For the purpose of this report, which is a study of structural patterns, no attempt has been made to justify each trend selected as an actual mapped fault. Many trends do coincide with mapped faults; many follow a similar orientation, and many trends may be as yet unmapped faults. It is noted that many mapped faults have a tortuous surface expression and appear to be-fracturing along several intersecting parallel zones of weakness, forming a zig-zag rupture along alternate en echelon sets.

Where two regional trends intersect, there often appears to be a mutual offsetting of both trends. Many if not all intrusive centers appear to occur at the intersections of several regional trends. The offsetting may be apparent as a result of the dip of structures, but if it is real, the mutual offsetting may have important consequences.

Figure 2 shows the location of the area in north-central Utah chosen to illustrate the selection and location of structural trends discussed in this paper. Any area of equivalent size in the Basin-Range province would be equally suitable. While the larger structural trends, as shown on Figure 1, are most easily traced on the 1:1,000,000 scale ERTS-1 mosaics of the states of Utah and Nevada, the imagery of this area has been enlarged to study in more detail several individual ranges in the Basin-Range province.

Figure 3 is part of ERTS-1 frame E 1015-17415-7 enlarged to a scale of 1:250,000 to make it possible to correlate directly the structures seen on it with a geologic map of the same scale. The area includes the Stansbury and Oquirrh Ranges, between Great Salt Lake, to the north, and Utah Lake, to the east. The structural trends are traced from the imagery on a transparent overlay; the overlays can be compared with the corresponding segment of the geologic map of Utah published by the Utah Geological and Mineralogical Survey in 1964. The lack of distortion of the ERTS-1 imagery makes this quite feasible.

Figure 4 shows a tracing of several orientations of regional trends photographed over the imagery of the Stansbury and Oquirrh Ranges. (Dotted lines mean that the trends are less obvious). The trends appear to offset each other where they intersect. The trend southeast from the upper left corner appears to be offset right laterally in several places as it crosses the alluvium-filled basin between the ranges and then follows along the southwstern boundary of the Oquirrh range for some ten kilometers. The trend is traced across the alluvium along a slight color offset which may represent a bench and/or soil-change. Inside the ranges, the trends are traced along strike valleys, drainages, structural offsets, and color changes.

ARCUATE TRENDS

As noted, many of the trend continuities have a regular change of orientation. They are tangential to a circular segment, and may occur in concentric sets. These are called arcuate trends. They are usually found as a semicircle (or less), though a few can be traced for a full circle. The full circles may be offset along radial regional trends, as can be seen on Figure 5. Across the states of Nevada and Utah, the arcuate trends can vary in diameter from a few hundred meters to many hundreds of kilometers; some very large diameter trends (>1000 kilometers) appear to be province boundaries.

I became aware of the smaller diameter (less than 50 km) arcuate trends after repeatedly finding and discarding them, since I was at the time looking for continuities with a single orientation. I finally decided to see if they had any structural significance of their own. Comparison of tracings of randomly oriented arcuate trends showed that they were frequently geologic as well as structural and geomorphic boundaries, that they often occurred in concentric patterns, as well as a baffling variety of sizes and relationships, and that there seemed to be a relationship between the smaller arcuate trends and the regional trends. I have found that the best way to work with them is to look for single sets having common centers, or having a common diameter.

They are not particularly easy to see unless they are major geomorphic boundaries. Many follow a structural grain rather than a distinct lineation. Repeated tracings of such areas will find lines concentric to but not necessarily identical to the original tracing, indicating that they represent a zone of movement rather than a distinct fracture of the crust, possibly comparable to the "soft zone" or broad transform fault zone suggested by Tanya Atwater (1970). The movement appears to reemphasize structures of a certain orientation and to offset crossing structures. There may not be much movement at any particular place or along any particular lineation; rather the total movement appears to be distributed over the series of concentric lineations. There also appears to be more movement on the larger diameter arcuate trends, both vertically and horizontally, than on smaller trends.

Figure 5 shows one of a number of possible sets of arcuate trends traced over the ERTS-1 imagery in the Stansbury-Oquirrh Ranges. Some of the arcuate trends follow curving drainages in the alluvium of Rush Valley between the southern parts of the ranges; others follow ridges, canyons, and smaller drainages within the ranges and along the range boundaries.

Figure 6 shows the correlation of this particular arcuate trend set with the mapped geology of the Stansbury and Oquirrh Ranges. Some of the arcuate trends follow range boundaries, some cross the ranges and the alluvium; some follow geologic boundaries, and some show no geologic relationship, as that through the Oquirrh formation in the southeastern Oquirrh Mountains. I have traced a few cross trends to show where the arcuate trends appear to be cut off or displaced.

The small curve on the right appears to be a center of some of the concentric trends I have traced on this illustration. On the image, the small trend defines a darker area within volcanics over Pennsylvania-Permian Oquirrh formation which is not shown as a geologic structure on the geologic map. It is an area of very complex drainage which can be traced as a series of very small, overlapping arcuate trends.

CENTERS

On Figure 7 I have traced another "center," east of South Mountain between the two ranges, and located arcuate trends which appear to be concentric to it. Here some of the trends are traced diagrammatically as smooth curves. Those in the central Stansbury Range appear to be truly concentric, but not those in the Oquirrh Range, indicating that there has been dislocation and a different structural history. Here, again, the center is a series of overlapping very small arcuate trends, as if there were not just one, but a grouping of centers. I have also traced some of the regional trends radial to the center (or centers). The offsetting of these trends at their intersection is evident.

There is also offsetting of the arcuate trends in the southern Stansbury Range along northeast by east trends and to the north along northwest by west and northwest trends. The more complex structure of the Oquirrh Mountains suggests overlapping of several arcuate trend sets having separate centers. Figure 8 relates this set to the mapped geology, and indicates that the arcuate trends may have some close relationship to the Basin-Range boundaries.

KNOTS

Wherever trends of relatively large (greater than 30 kilometers) diameter intersect other trends, there is some offsetting apparent on the ERTS-1 imagery which shows up as a "knot" of disturbed crust, the diameter of which is equal to the amount of offset. A number of these have been compared with the mapped geology, located on Army Map Service photography (1 mile to 1 inch scale), and a few have been examined on the ground*. Smaller knots (less than 1 kilometer in diameter) have been located at springs, ponds, heads of drainages, or intersections of several drainages, kinks, amphitheaters or coves, knobs, or ridges. Those greater than one kilometer in diameter have been identified as larger amphitheaters or knobs defined by curving drainages; intrusive centers; sedimentary basins, or swamps. A few are mapped as older (Paleozoic) rocks surrounded by younger rocks or as having complex arcuate faulting. On the ground, these areas are complexly fractured and jointed. The center shown on Figure 8 is a complex of "knots," with braided drainage to the north, swamp to the south, and outcrops of Pennsylvanian-Permian rocks to the east and west.

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* A number of anomalous structures have been reported in the literature where localized complex faulting is unexplained. It is possible that the offset cross fault relationship, or a "knot," may explain the anomaly.

There appears to be some correlation between the relative direction of offset of the controlling structures and the type of disturbance found at the centers or knots. Where both structures appear to offset in the same relative direction (both right lateral or both left lateral), the knot or center appears to be a tensional feature, as a basin or spring. Where one structure is offset right laterally and the other left laterally, the disturbance appears to be compressional, creating a complexly fractured uplift or knot. This relationship is tentative, not proven; field work is planned to check it. It is interesting that the patterns described appear to persist in spite of erosion and sedimentary deposition.

FIELD WORK

The field work so far has been limited to several brief trips to identify on the ground some of the structures traced on the ERTS-1 imagery but not shown on geologic maps. The results are more permissive than conclusive: wherever rock outcrops were located on the proposed trend, there is fracturing and jointing with the hoped for orientation as well as many other orientations. Since the initial evidence for selecting the trends is geomorphic, it cannot be used as "ground truth" for proving their existence.

One (possibly very old) trend was located on the imagery between Deer Lake Reservoir, in Heber Valley, and Olympus Cove on the Wasatch Front in Salt Lake Valley in Utah. Positive evidence for the existance of this N 50° W trend included an unmapped breccia zone in a new road cut about 1/2 mile NW of the north end of Deer Creek Reservoir; valley alignments; a spring and mineralization on the supposed trend in Little Cottonwood Canyon, and permissive structural orientations.

BASIN-RANGE PATTERNS

A tracing of regional trends from ERTS-1 imagery photo mosaics of Utah and Nevada (1:1,000,000 scale) indicates that wherever regional trends of different orientations intersect and offset each other, there is a center of crustal disturbance. Some of these centers appear to correlate with the Tertiary intrusive centers in Nevada of Albers and Kleinhampl (1970).

The major lineations in Nevada described by Rowen and Wetlaufer (1973) appear to be segments of regional or large arcuate trends.

Each offset trend intersection in the Basin-Range province appears to be the center of a concentric set of arcuate trends. The arcuate trend sets overlap neighboring sets and control the boundaries of the Basin-Range structures. Figure 9 is a compass design showing such an overlapping of trends. This may be compared with Figure 10, a tracing of the northeast corner of Nevada from the ERTS-1 photo mosaic on a 1:1,000,000 scale, showing a similar pattern. The main center is between Mountain City and Yarbridge Peak in Elko County. The Ruby Mountains are in the south-central part of the tracing. Figure 11 is another compass drawing of a number of overlapping trend sets to be compared with Figure 12, a tracing of arcuate trends of a uniform diameter around a number of centers in central Nevada, from the same photo mosaic, with Walker Lake in the lower left and Ryepatch Reservoir at the upper left.

In summary, the arcuate trends:

1. Are traced from geomorphic patterns visible on ERTS-1 imagery.
2. Are defined by straight structural trends which are tangential to a regular curve.
3. Range in diameter from a few meters to many hundreds of kilometers.
4. Occur in concentric sets.
5. Have centers which occur at the intersecting and mutually offsetting trends of a larger order of magnitude.
6. Overlap and offset trends having different centers.
7. May be geologic and structural as well as geomorphic boundaries.
8. Appear to be traces of disturbance of the earth's crust.

A hypothesis to account for the arcuate trends requires several basic assumptions:

1. The lineations visible on the surface of the earth which are not man-made are controlled by rock structures. Movement creates zones of weakness which are more readily attacked by erosion. If there is any coherent pattern to the structures, these patterns should be evident in the geomorphology of the crust.
2. The crust of the earth floats on a plastic (aesthenospheric) layer (Mackenzie, 1969).
3. The crust of the earth is incompetent and easily fractured (Hubbert, 1945).
4. There appears to be a systematic linear structural pattern in the earth's crust, along which movement can take place, either vertically or horizontally (Badgley, 1965),(Khain and Muratov, 1969).

REACTIVATED FAULT RELATIONSHIPS

Wherever the regional trends intersect in the area studied for this report, most if not all appear on the ERTS-1 imagery to be mutually offset. Mutual offsetting may be apparent as a result of vertical movement which is not measurable on ERTS-1 imagery, or it may be real. A number of authors have described reactivation of Precambrian structures at later periods of tectonic activity (Anderson, 1948), in the Bagdad District of Arizona; (Richard and Courtright, 1954) in the Silver Bell District; (Badgley, 1965) in Colorado. It seems quite possible that changing stress patterns would reactivate old zones of weakness. An examination of the offsets of two intersecting trends shows that the trends may be either offset in the same relative direction (right lateral: right lateral or left lateral: left lateral) or in the opposite relative direction (right lateral: left lateral). There may be as many as six trends of different orientations intersecting at a given center.

SAME RELATIVE DIRECTION OF MOVEMENT

Where two faults have the same relative direction of movement, the relationships as first one, then the other moves, are shown in A in Figure 13. It is assumed, to simplify the explanation, that only two vertical faults are intersecting and that their movement is horizontal, Movement on the east-west fault offsets the north-south fault, later movement on the north-south fault stretches the space between them with subsequent gravitational adjustment by slumping or landsliding. The result is a basin-shaped depression, if in ductile material, or step-faulting if in brittle material, as in B of Figure 13. The movement is similar to toreva block motion, which is rotation of a block of crust on a horizontal axis. Where there is also vertical motion along the controlling faults, the uplifted blocks are especially susceptible to such slumping. The rotated blocks would tend to be arcuate in plan view, with a curved undersurface, dipping toward the fault intersection. Their maximum diameter would be directly proportional to the amount of movement, vertical and horizontal, along the controlling faults.

Such slumping may in part account for the basin depressions in the Basin-Range province. An example may be the Salt Lake Valley, which is semicircular on the east side, controlled by a deep fault which may (though there is no such fault mapped) extend through the center of the valley, following the drainage of the Jordan River. Tracings of arcuate trends follow the basins, as shown in Figure 14 which shows concentric trends in the Central Wasatch Mountains to the east. Utah Lake is in a similar basin, and others can be traced in the adjacent intermontane valleys. It is possible that fracturing was initiated by compressive centers, then released by a change of stress to tensional centers. Dr. Thomas Mitchum (1974) explains arcuate structures in the southwestern United States as "collapse into large gaping fissures as the fissures develop within the fault systems." This tension-collapse would appear to be similar to the type of adjustment I hypothesize. Perhaps pulling apart on many fault intersections could account for the development of some large continental basins and geosynclines. If the faults are very deep, it is possible that such dilation could provide conduits for basic igneous activity. It has been suggested that arcuate trends are the result of igneous doming; instead might the doming follow dilation and the rise of low-density magmatic material at many centers?

Such a cross-fault mechanism might provide an alternate explanation of the areas of tension or spreading centers described by Pakiser (1960) as the over-lapping ends of strike-slip faults where such become loci of volcanic activity, as in Owens Valley in California. Elders et al. (1973) describe a similar relationship in the Imperial Valley. Figure 15 shows Elder's spreading center compared with the fault intersection center. Tracings of structures from ERTS-1 imagery of this area indicate that such fault intersections do exist.

OPPOSITE RELATIVE DIRECTION OF MOVEMENT

Where the faults have the opposite relative direction of movement, the result is a blockage of the motion of the second fault by the offset of the first, as shown in Figure 16. Crushing, thrusting, or buckling may take place at the offset edge, with possible vertical relief. As movement along the fault continues, the moving blocks will bypass the obstructed block by rotating around it as shown at "B" in Figure 15, creating an arcuate fracture trace. Repeated friction and stress release as movement continues may build up the pattern of concentric trends. Build up of heat in deep zones of crushing might cause melting of crustal material and provide centers of silicic igneous activity.

If the faults are vertical, the compressed block could be a vertical cylinder; if not, the axis of the compressed block would be tilted and its rotation would show up as thrust, normal, strike-slip and scissor faults. This motion could account for the structural and geologic offsets found across arcuate trends. At depth the movement may be plastic deformation, resulting in folding rather than fracturing.

The ultimate diameter of the arcuate-trend bounded blocks would seem to depend on the amount and depth of movement along the controlling faults. Wherever possible, the fracturing would try to follow pre-existing zones of weakness, thus accounting for the tangential trend relationships. And as movement along a controlling fault continues, the semicircular concentric trend-set on one side would be offset from the set on the other, creating the pattern shown on Figure 17 at "A." In addition, reactivation of other faults at the same center might offset pie-shaped segments of the first arcuate trend set and create another set with a new slightly overlapping center over the first set, as at "B." These patterns can be seen in the center on Figure 7.

INTERACTING BLOCKS

These relationships may be similar to that proposed by John F. Dewey (1972) to explain the interaction of tectonic plates on a global scale. The movement of segments of crust on the surface of a sphere must be rotation around a pole (but the pole is not necessarily located on the segment). The rotation of adjacent segments causes them to pull apart (rift) or overthrust (subduct), with strike-slip tearing along latitudes of rotation because of different rates of rotational velocity.

The latitude-of-rotation faults are transform faults if they are the result of rifting and spreading (formation of new crust). Within a segment of continental crust, such spreading has been suggested by Davis and Burchfiel (1973); Liggett and Ehrenspeck (1974).

Elders et al. (1973) has suggested that there is a conflict between the northwesterly moving Pacific Plate and the southeasterly moving American Plate in the Salton Sea area of Southern California, with rifting as they pull apart.

The regional trend patterns suggests that the relationship is more complex and that at least four plates are or have been competing for possession of the crust in any given area. If each of the parallel-concentric sets of regional trends represents the latitude-of-rotation tearing of a large moving segment of crust, then each segment has had at different times several different centers of rotation and directions of movement. One rotating block in compression against another may try to add part of the latter to its own sphere of influence and to change the motion of the captured fragment. The effect would be a taking over of a part of the adjacent block along a system of strike-skip faults rather than rifting or thrusting, as shown in Figure 18. But if both blocks are in motion, offsetting at intersections with latitude-of-rotation faults of the captured block would set up the cross-fault relationships hypothecated in this paper, with localized rifting and thrusting or buckling and a resulting complication of the fault patterns on the surface of the crust.

BASIN AND RANGE STRUCTURES

John Stewart (1971) summarizes the theories currently discussed to explain Basin and Range structures. These are:

1. Tilting of large slabs of crustal material as a result of loss of lateral support.

2. Deformation as a result of strike-slip movement on conjugate faults.

3. Horst and graben structures formed as a result of deep-seated extension of the plastic substratum.

To these theories,which are not mutually exclusive, I would add the concepts of rotating blocks, cross faulting and block interaction. If the arcuate trends are, as proposed, fractures along latitudes of rotation of a moving segment of crust, the large-diameter trends may be proportionately deep and extend into the lower crust as basement shears. They may be zones of weakness even when deeply buried, and evidence of their position will show through the covering sediments, even when there has been no recent tectonic reactivation, because of the slight movement caused by tidal and rotational drag of the earth. (Badgely, 1965, p. 126-127). Thus the lineations or structural trends show up on ERTS-1 imagery even when they are not readily discernable on the ground.

Reactivation of movement along some of these deep fractures and their intersections with other sets of deep fractures appears to control the Basin and Range structures. Where the sets of intersecting faults have opposite relative direction of movement, compression at many intersections may cause concentric fractures of rotation and may create centers of siliceous igneous activity as well as thrusting, crushing, and buckling of the crust. The concentric fractures of one intersection overlap concentric fractures from adjacent compressive centers; rotation on tilted poles may cause tilting of the rotated blocks. A later change of stress orientation, perhaps caused by readjustment of the block to a new pole of rotation, may set up intersections with faults having the same relative direction of movement, create centers of tension and pull the crust apart along the older concentric fractures. The centers of dilation may provide conduits for basic intrusives and explain the high heat flow in the Great Basin.

Reactivation of faults of other orientations at the same centers could change the stress relationships many times during the readjustment of the movement of a block from one pole of rotation to another. This may be an explanation for the alternate compressive and tensile relationships described by T. B. Nolan (1935) at Gold Hill, Utah.

The translation of a segment of crust from one block to another may explain why seismic activity along strike-slip faults tends to be spread over a fairly broad strip of crust rather than along a single shear. It is possible that the present belt of seismic activity around the lower part of the Great Basin in Utah and Nevada (Figure 20) represents the present area of adjustment of the crust to a new block relationship, or that the seismic belt is an area of conflict between two blocks competing for control of the crust. The regional trend pattern on Figure 1 suggests a great deal of offsetting of the trend continuities and changes of orientation in the active seismic regions.

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25. Photo mosaic of Utah, ERTS-1 imagery, 1973, Dept. of Geogr., University of Utah (Bruce Keating).

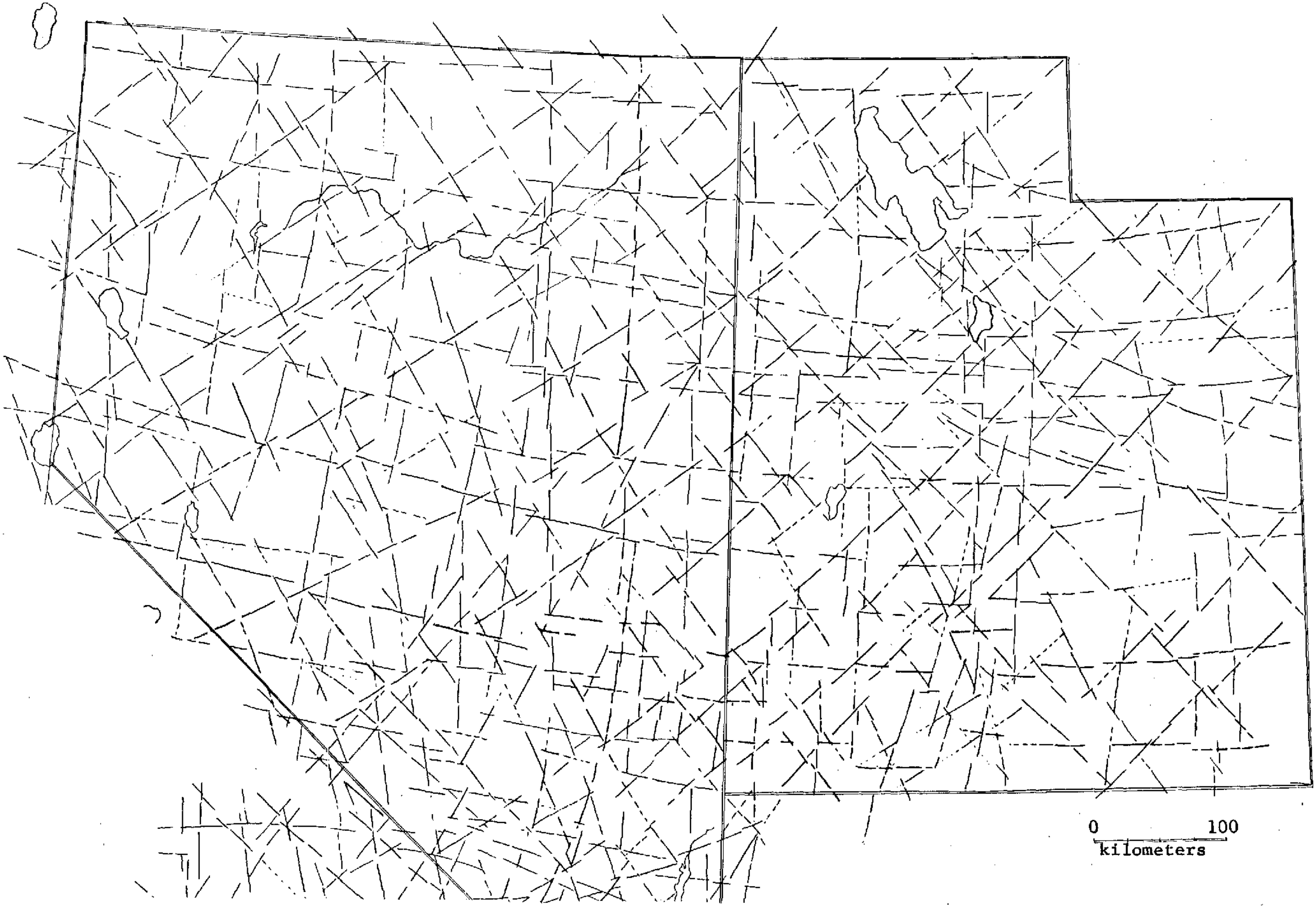


Figure 1. Regional Trends Traced from ERTS-1 Mosaics of Utah and Nevada.

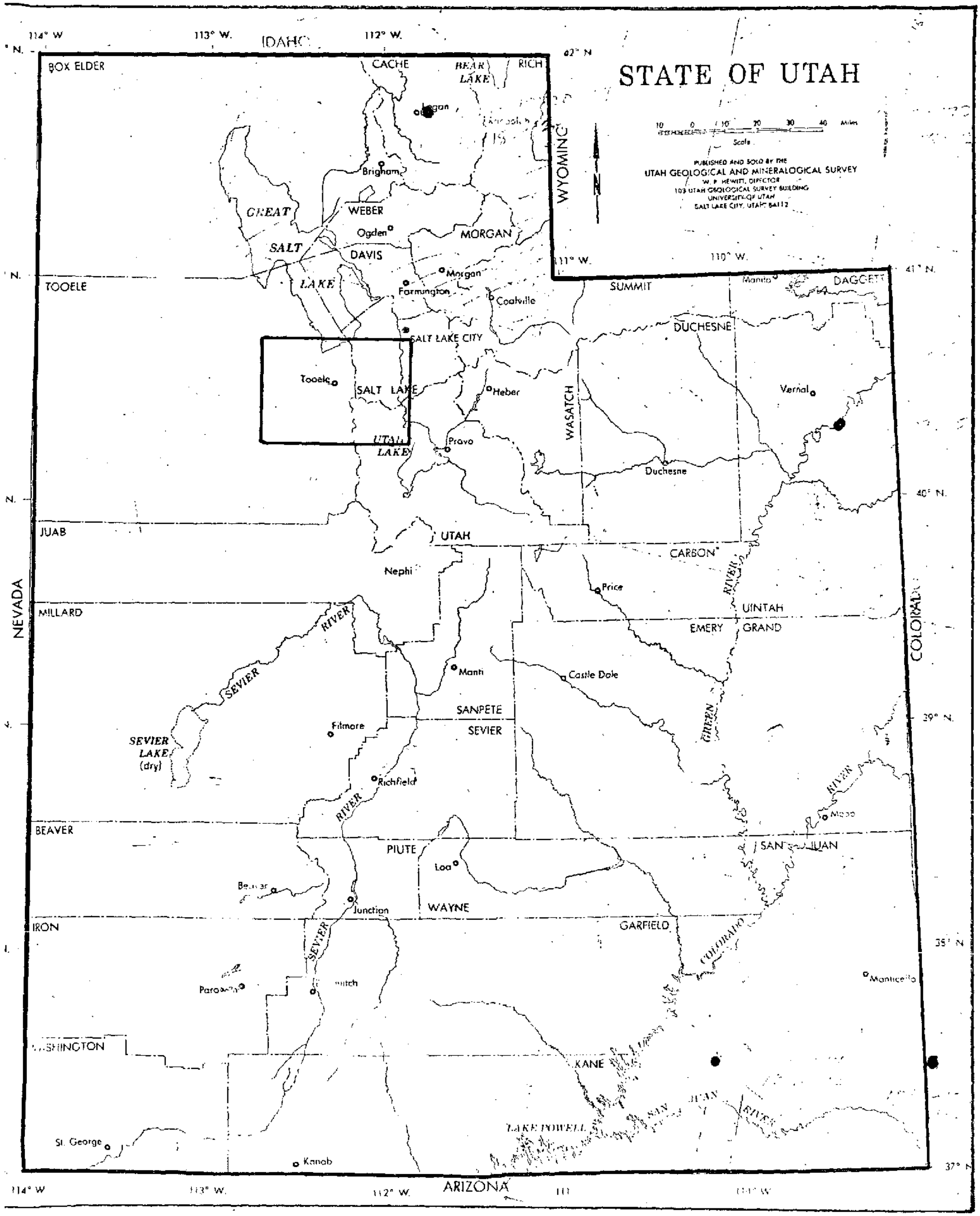


Figure 2. Location of ERTS-1 Imagery Discussed in Text.

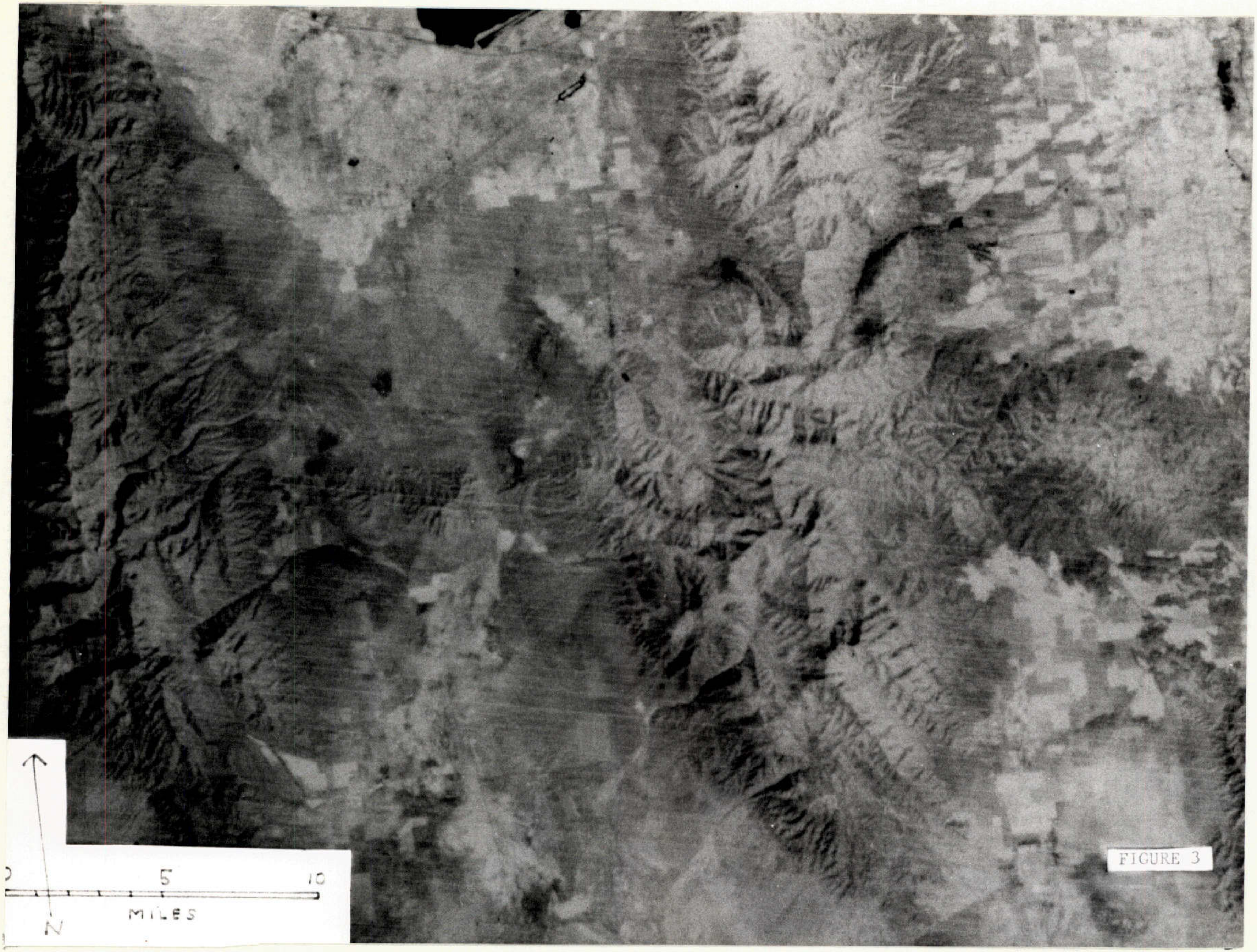


Figure 3. Enlarged Portion of ERTS-1 MSS Frame E-1015-17415-7 in North Central Utah.

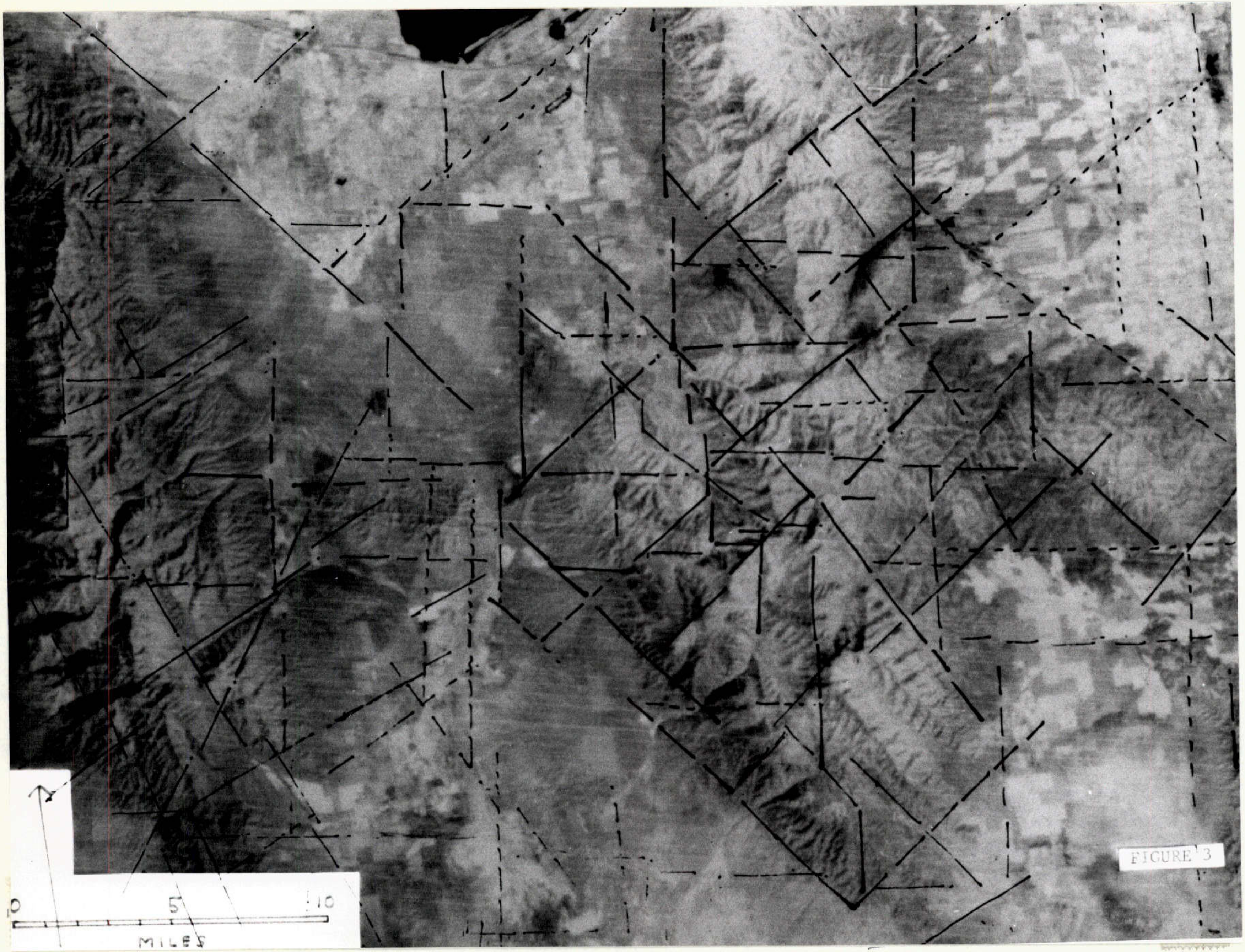


Figure 4. Regional Trends Traced over Figure 3.

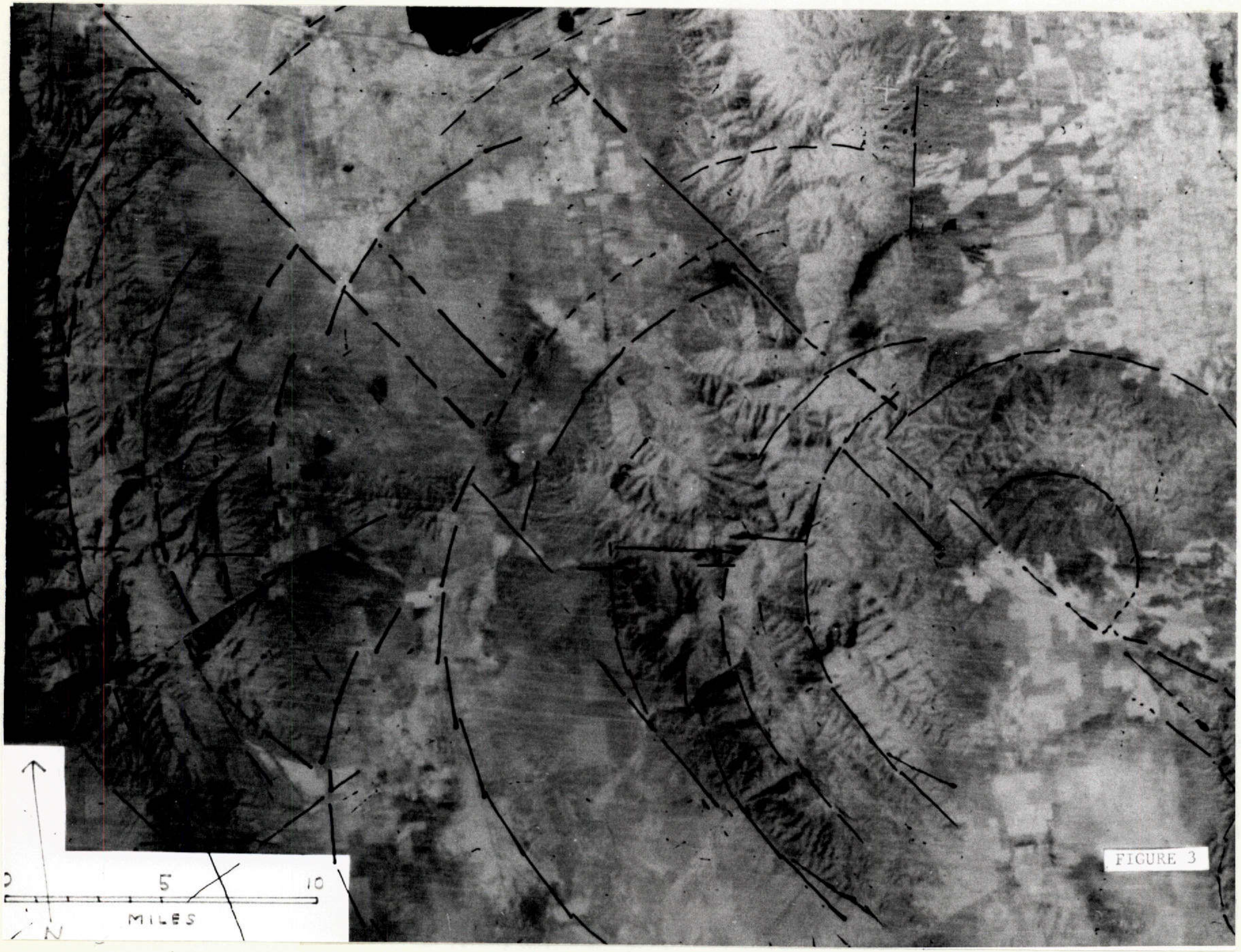


Figure 5. Arcuate Trends Traced over Figure 3.

Figure 6. Arcuate Trends Related to Geologic Map.

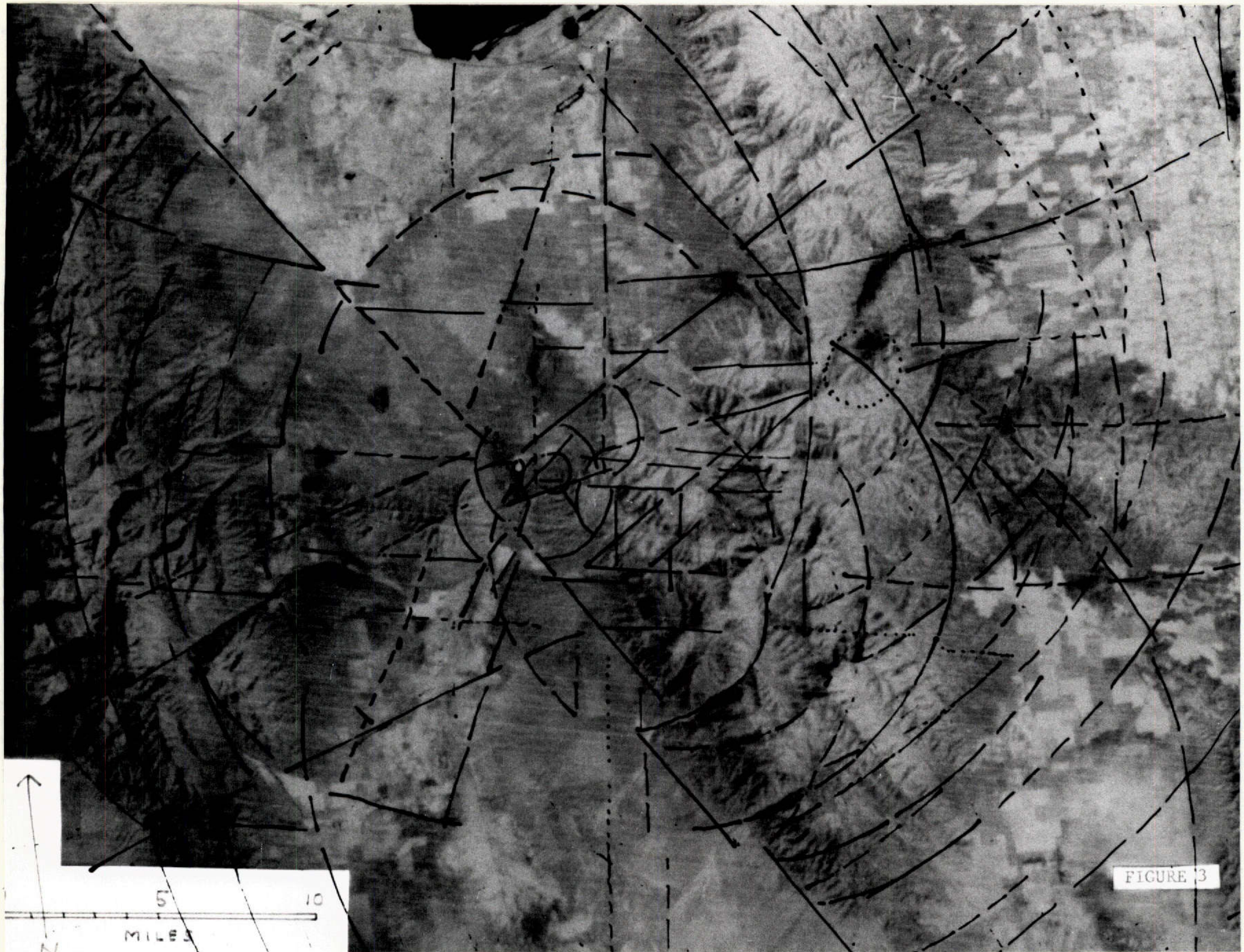


Figure 7. Center of Arcuate Trends Traced over Figure 3.

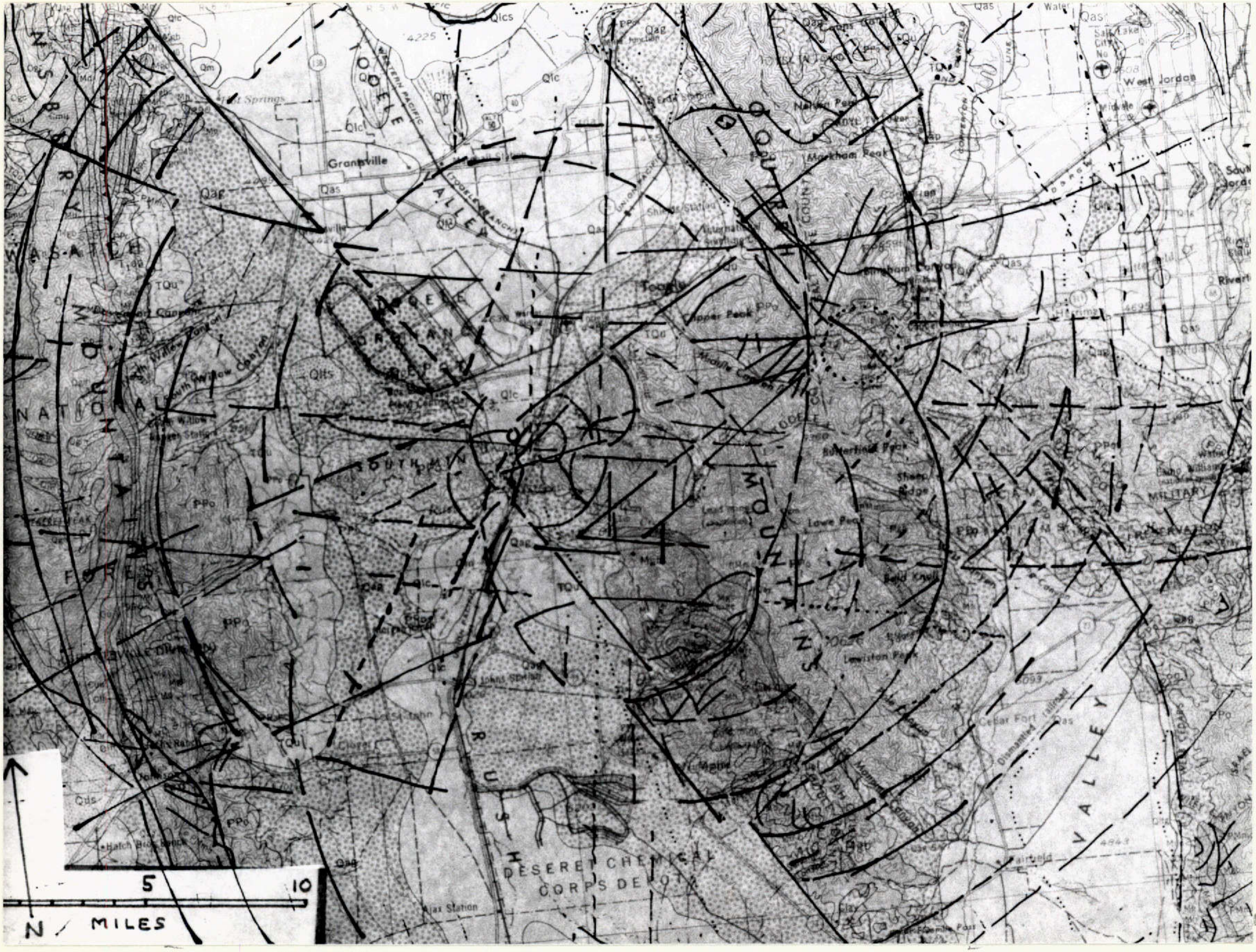
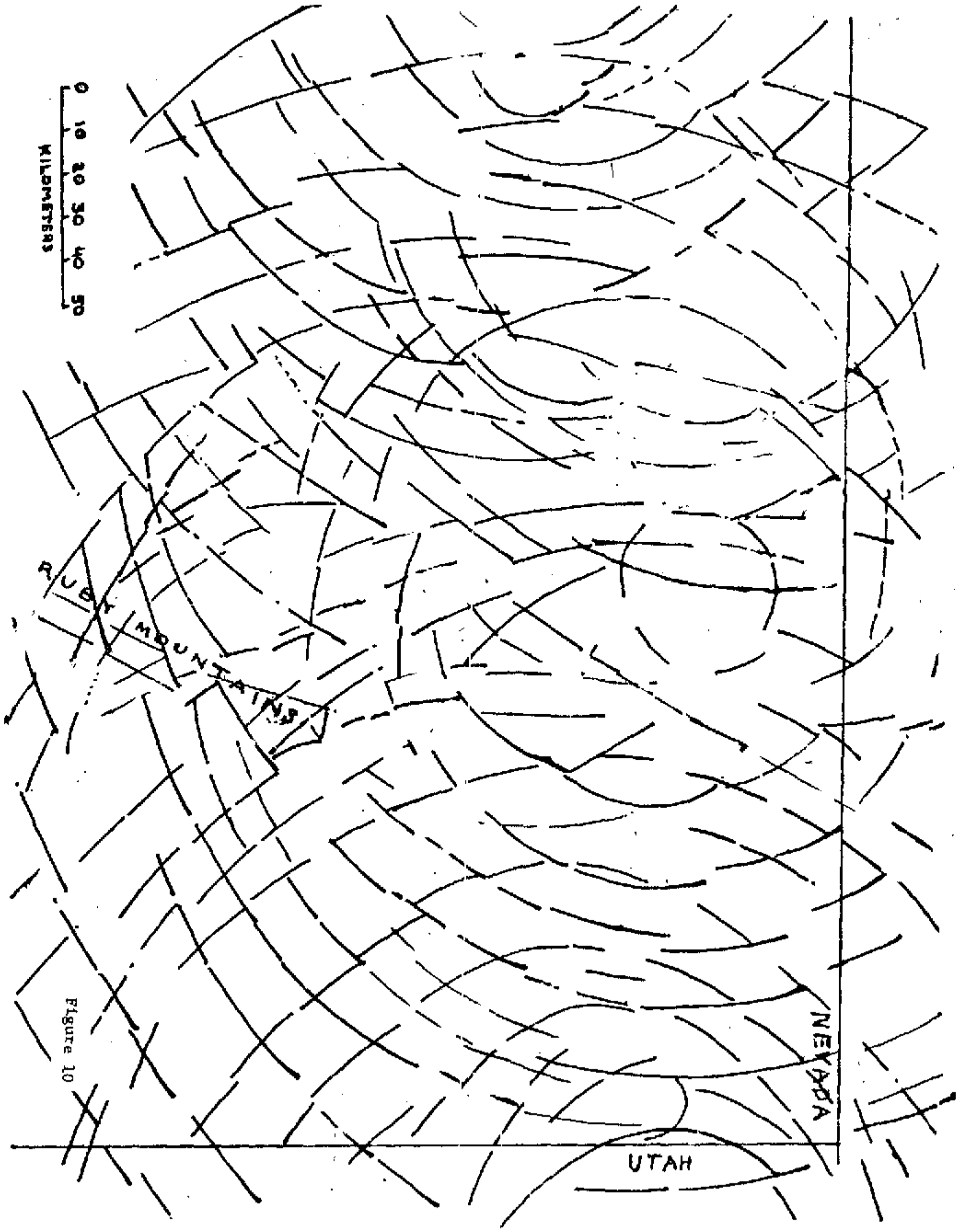
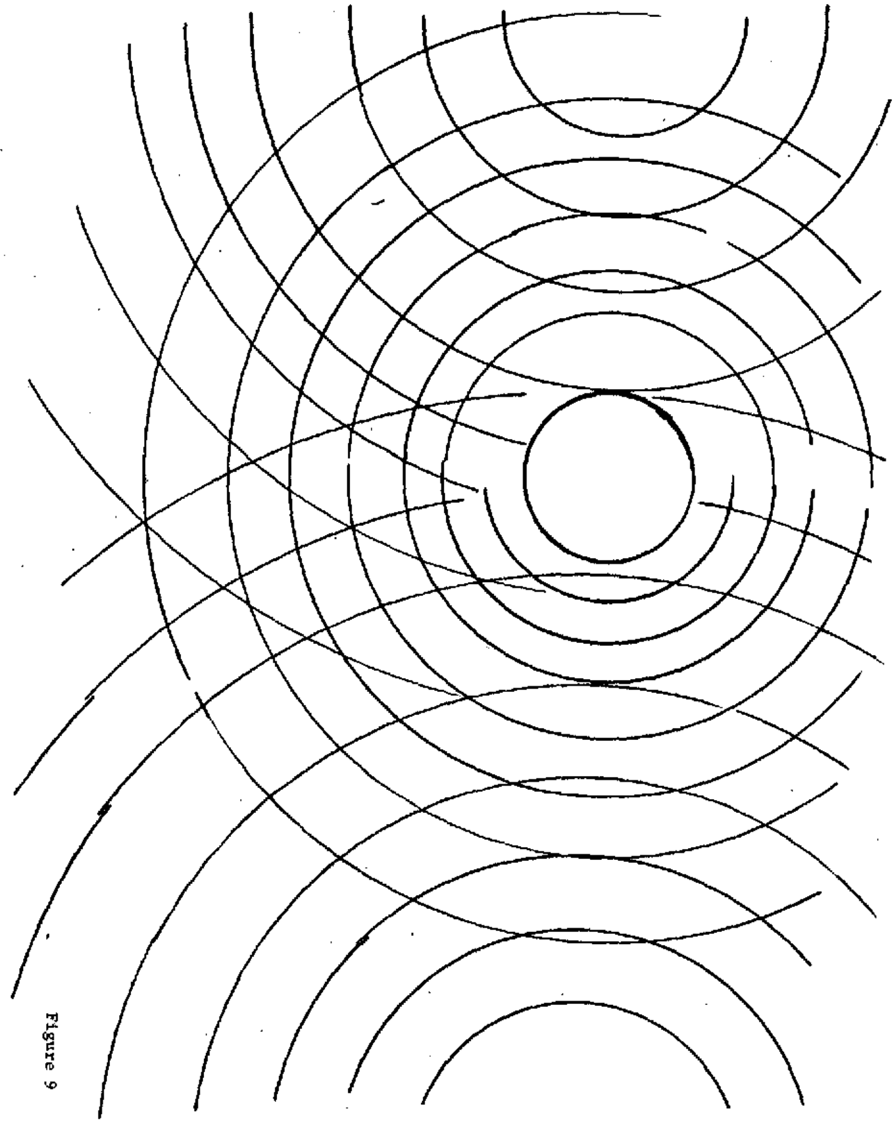


Figure 8. Center of Arcuate Trends Related to Geologic Map.





Figures 9 and 10. Compass Design of Overlapping Circles (Figure 9) Compared with Tracing of Arcuate Trends in NE Nevada (Figure 10)

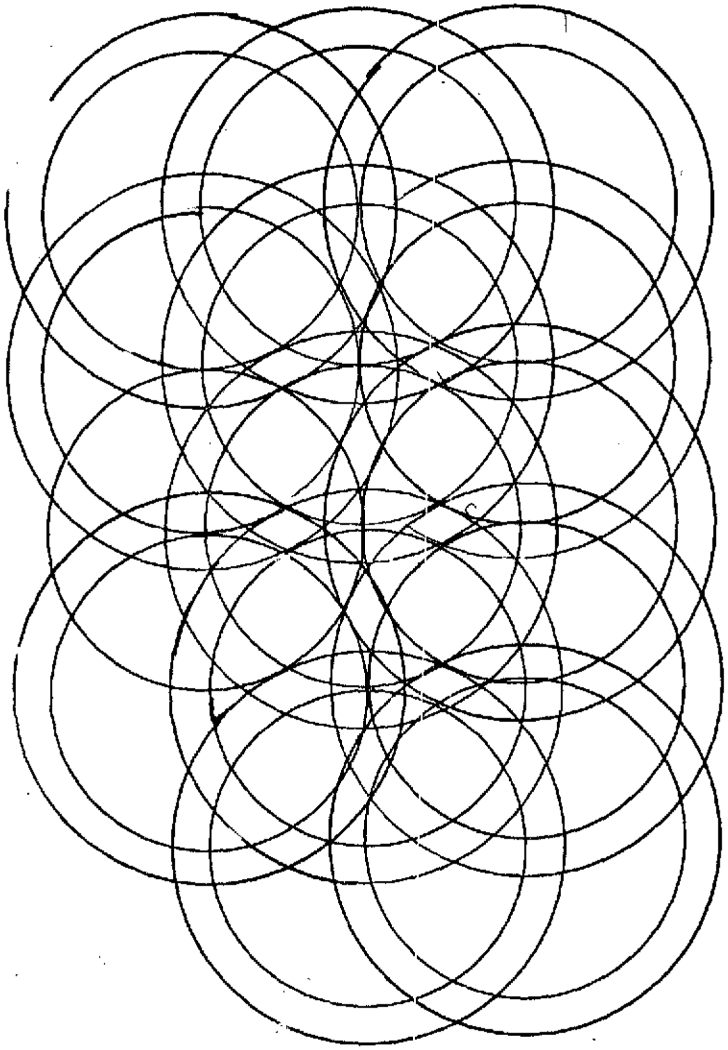


Figure 11

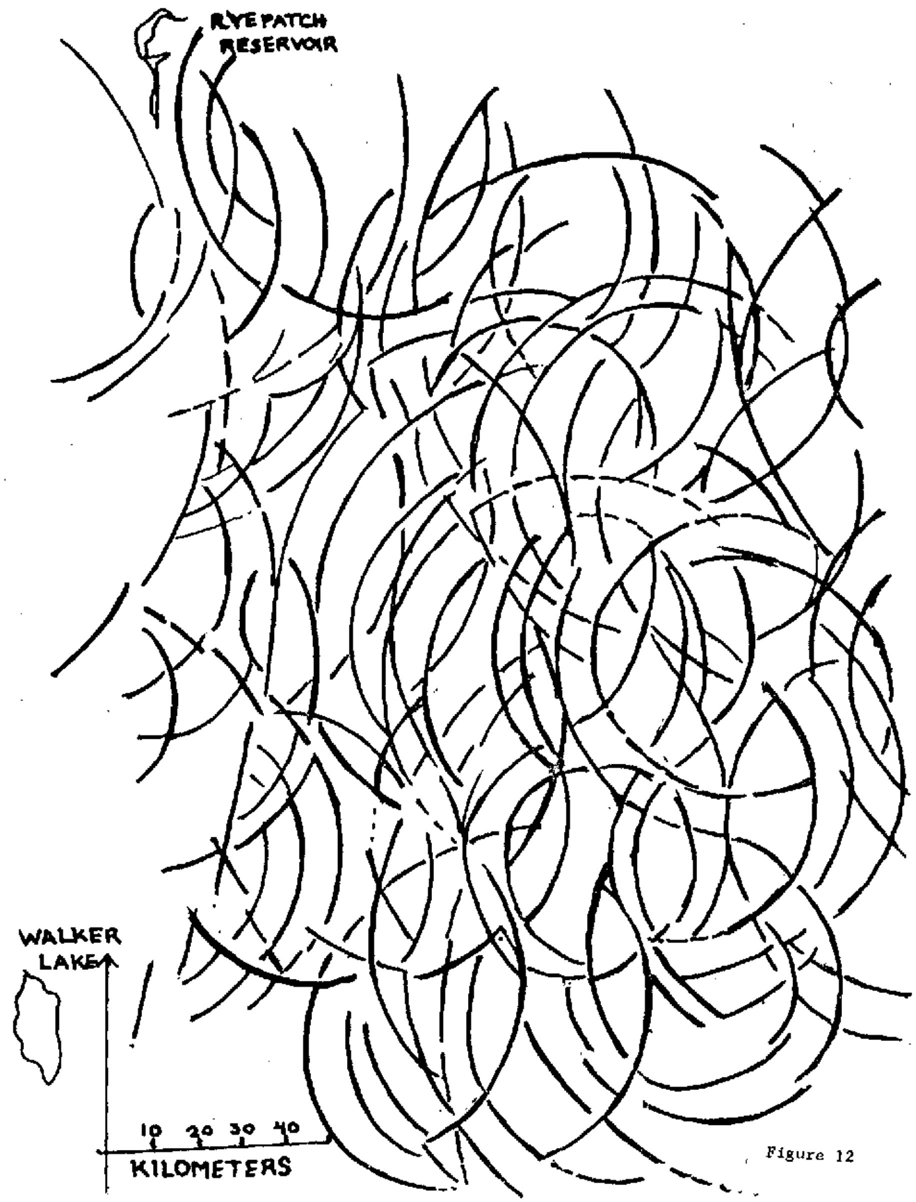
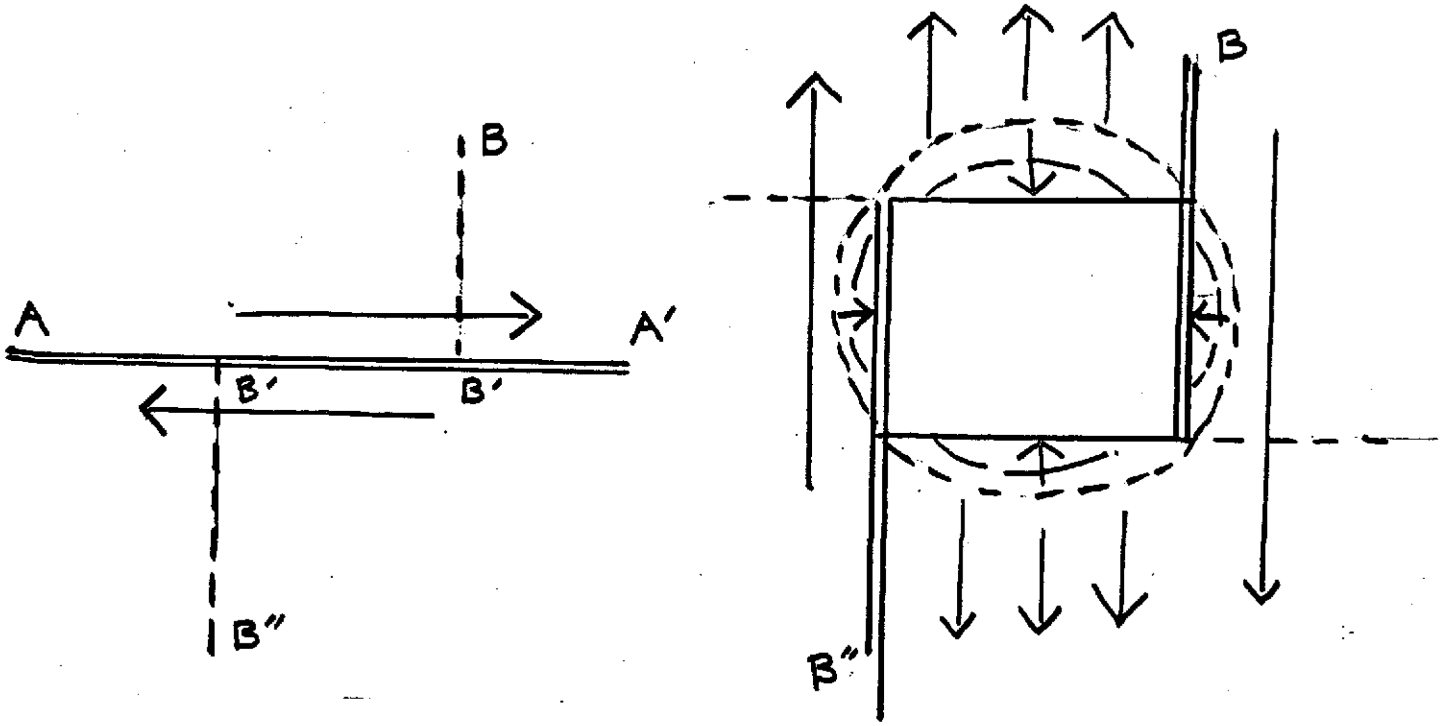
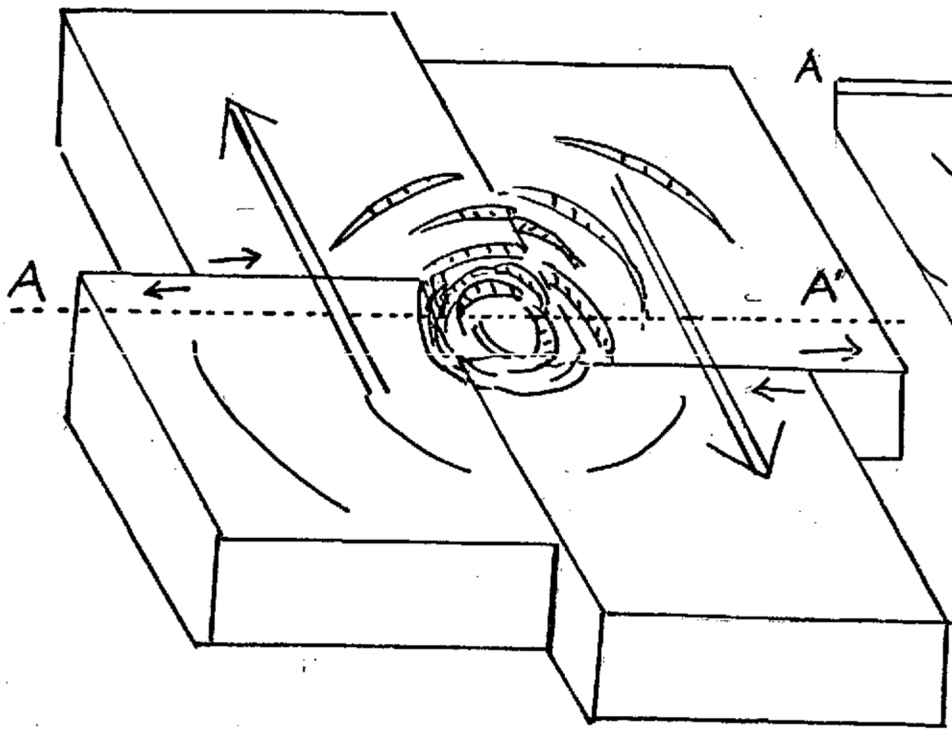


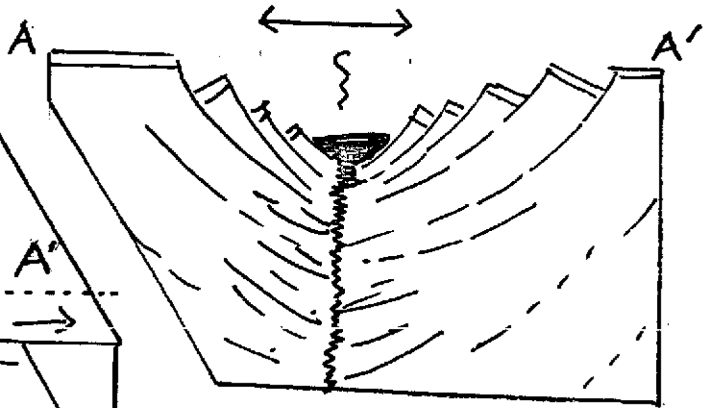
Figure 12

Figures 11 and 12. Compass Design of Overlapping Circles (Figure 11) Compared with Tracing of Arcuate Trends in Central Nevada (Figure 12)



A OFFSETTING OF TWO INTERSECTING FAULTS HAVING THE SAME RELATIVE DIRECTION OF MOVEMENT





TOREVA BLOCK SLUMPING

B Figure 13

Figure 14. Tracing of Arcuate Trends in the Wasatch Mountains
East of Salt Lake Valley, Salt Lake County, Utah.
from ERTS-1 1015-17415-7 scale same as Fig. 3.

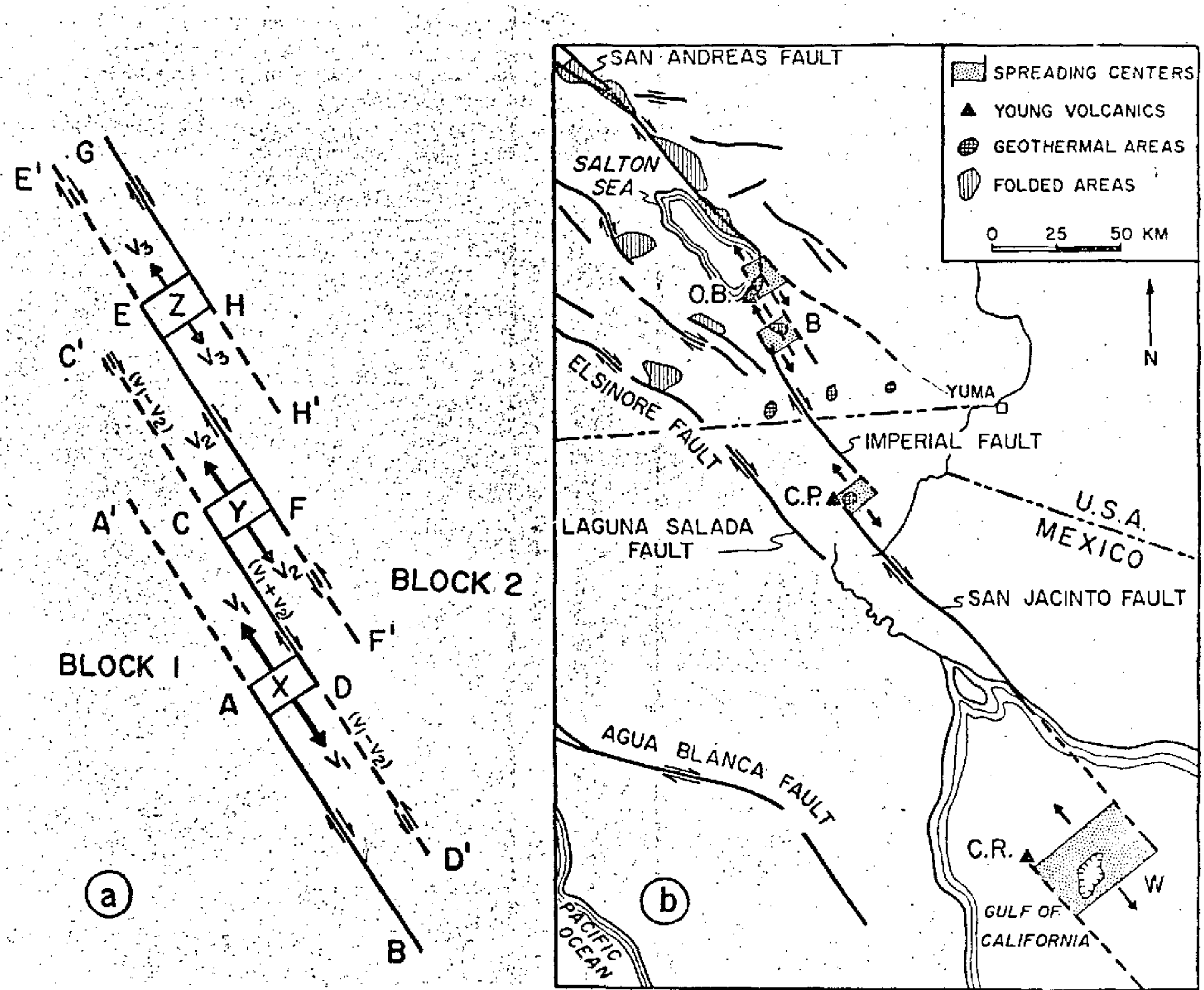


Fig. 7. Possible relations between strike-slip (transform) faults and spreading centers in the Salton trough. (a) Tensional zones or rhombochasms between en echelon strike-slip faults. *X*, *Y*, and Z are spreading centers between faults *AB*, *CD*, *EF*, and *GH*, with right-lateral motion. If these faults were en echelon in the opposite sense, compression would result between them. V_1, V_2, and V_3 are the spreading velocities on *X*, *Y*, and *Z*, respectively. If these velocities are unequal, the pattern is unstable. (See text.) (b) Postulated spreading centers, young volcanics, geothermal areas, and zones of intense folding and compression in Cenozoic sediments. *O.B.*, Obsidian Butte; *B*, Brawley geothermal area; *C.P.*, Cerro Prieto; *C.R.*, Consag Rock; *W*, Wagner Basin. Adapted from Lomnitz *et al.* (*43*, figure 3).

from Elders, et al, 1973

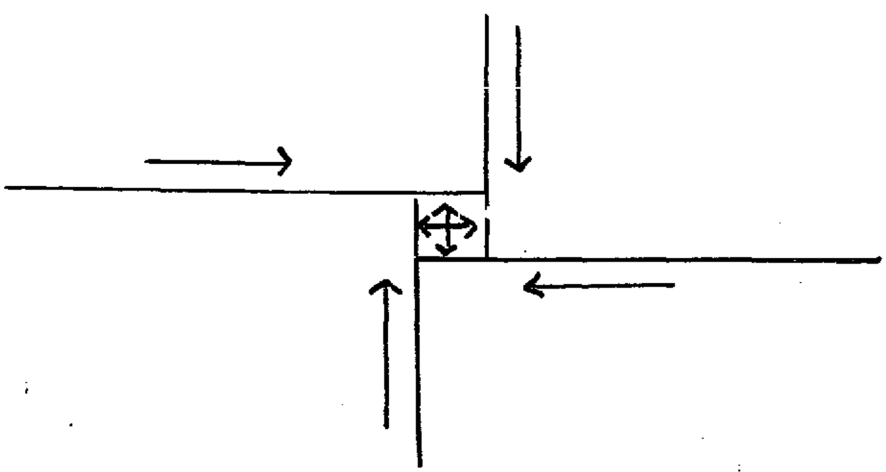
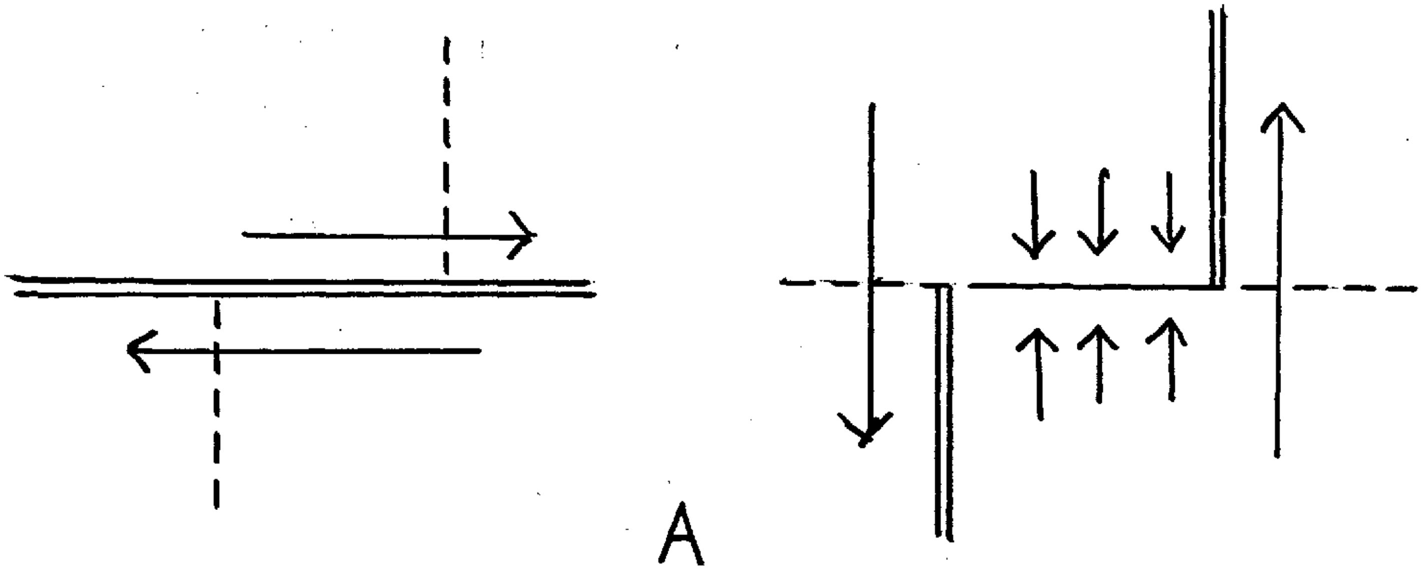


Figure 15 SPREADING CENTERS AND OFFSET FAULT INTERSECTIONS



OFFSETTING OF TWO INTERSECTING FAULTS HAVING OPPOSITE RELATIVE DIRECTIONS OF MOVEMENT

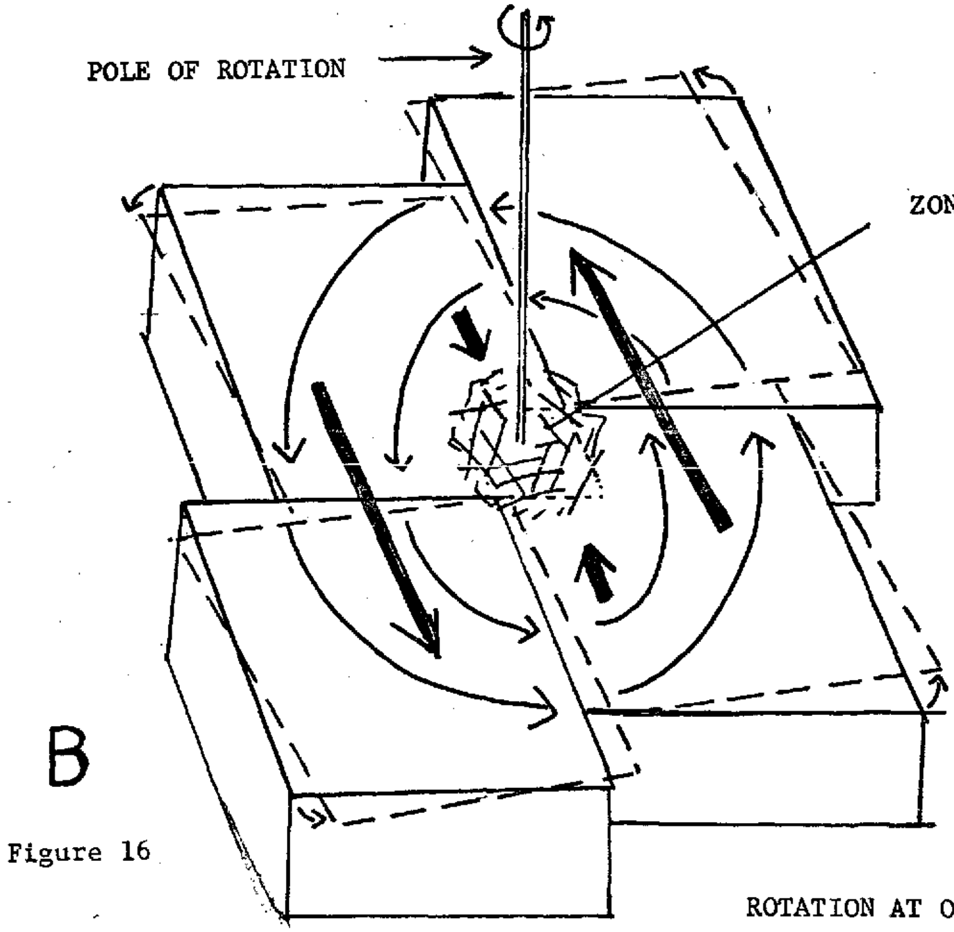
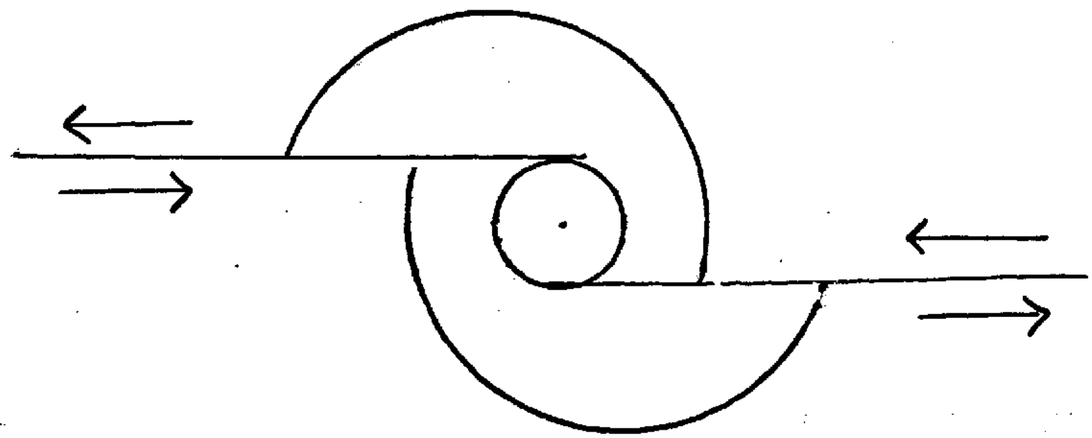
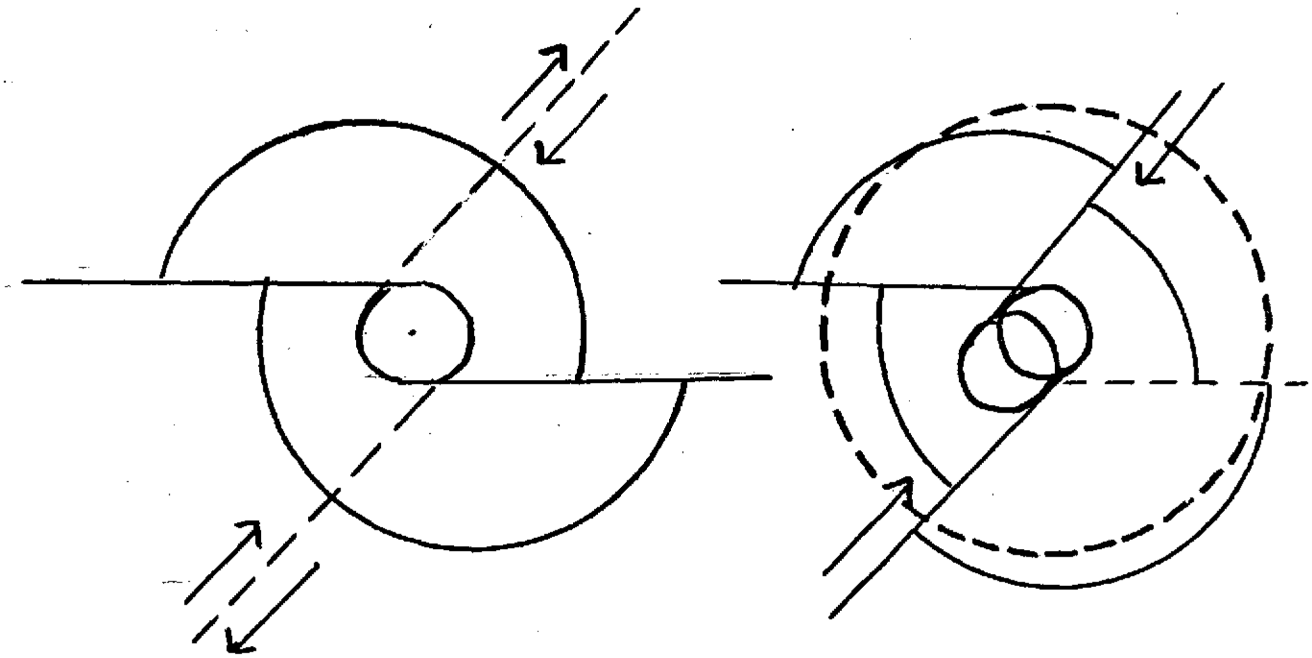


Figure 16

ROTATION AT OFFSET INTERSECTION

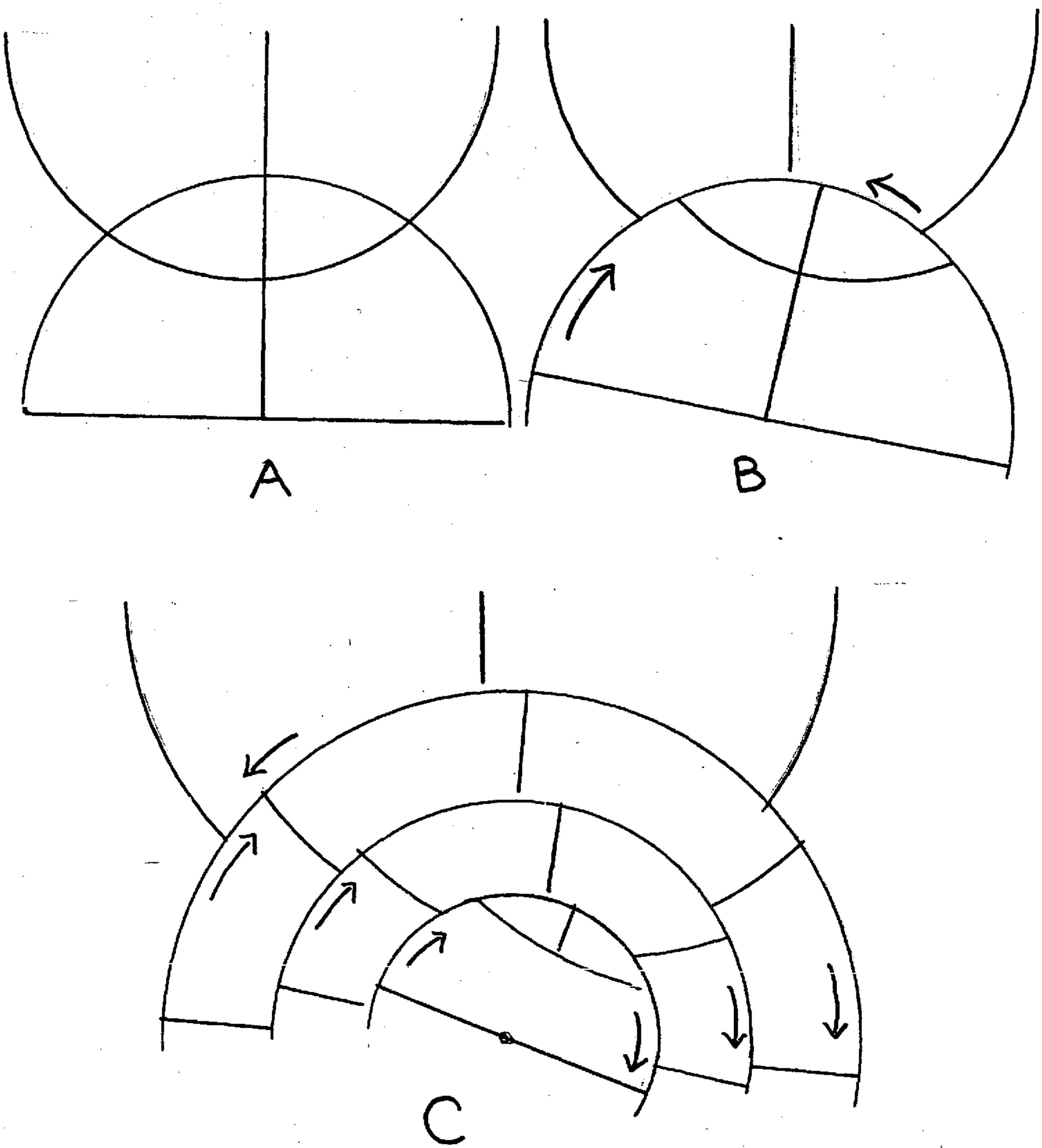


OFFSETTING OF CENTER AS A RESULT OF MOVEMENT ALONG FAULT



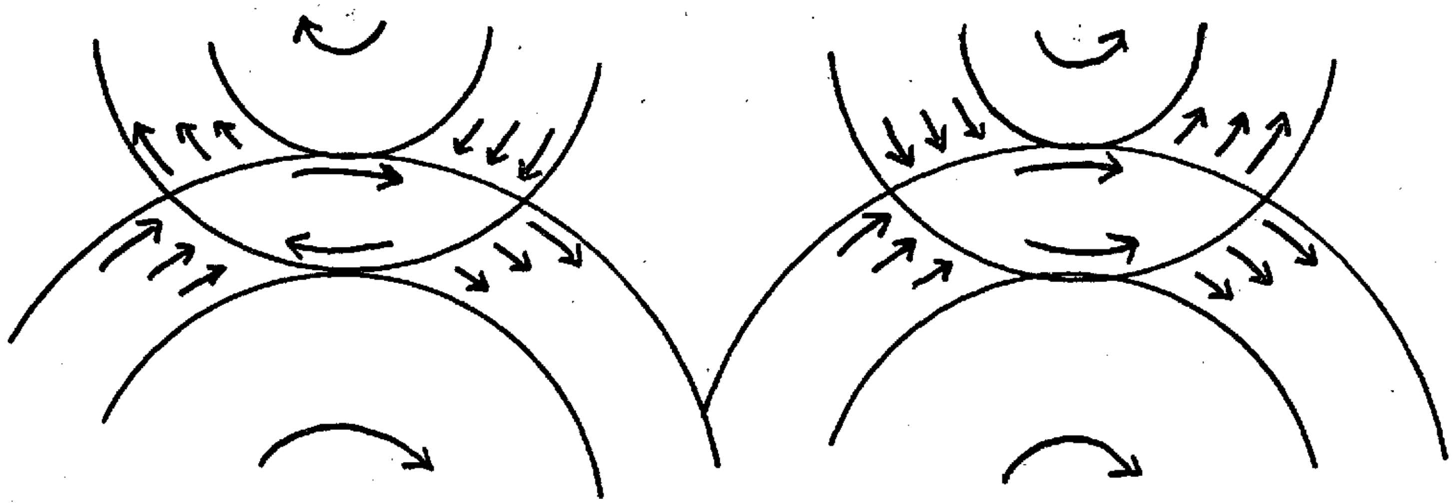
FURTHER OFFSETTING BY MOVEMENT ALONG SECOND FAULT OF ANOTHER ORIENTATION

Figure 17



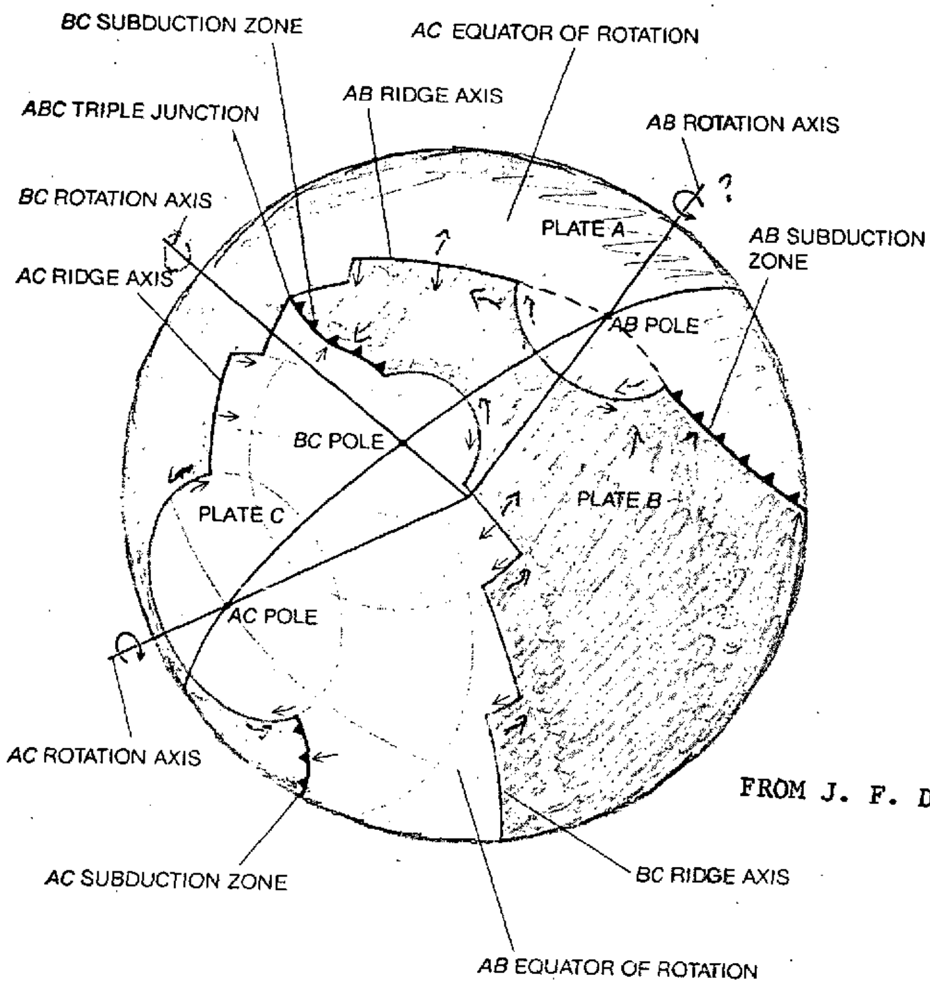
OFFSETTING OF ONE ARCUATE TREND BY A ROTATING BLOCK

Figure 18



SAME RELATIVE DIRECTION OF ROTATION   OPPOSITE RELATIVE DIRECTION OF ROTATION

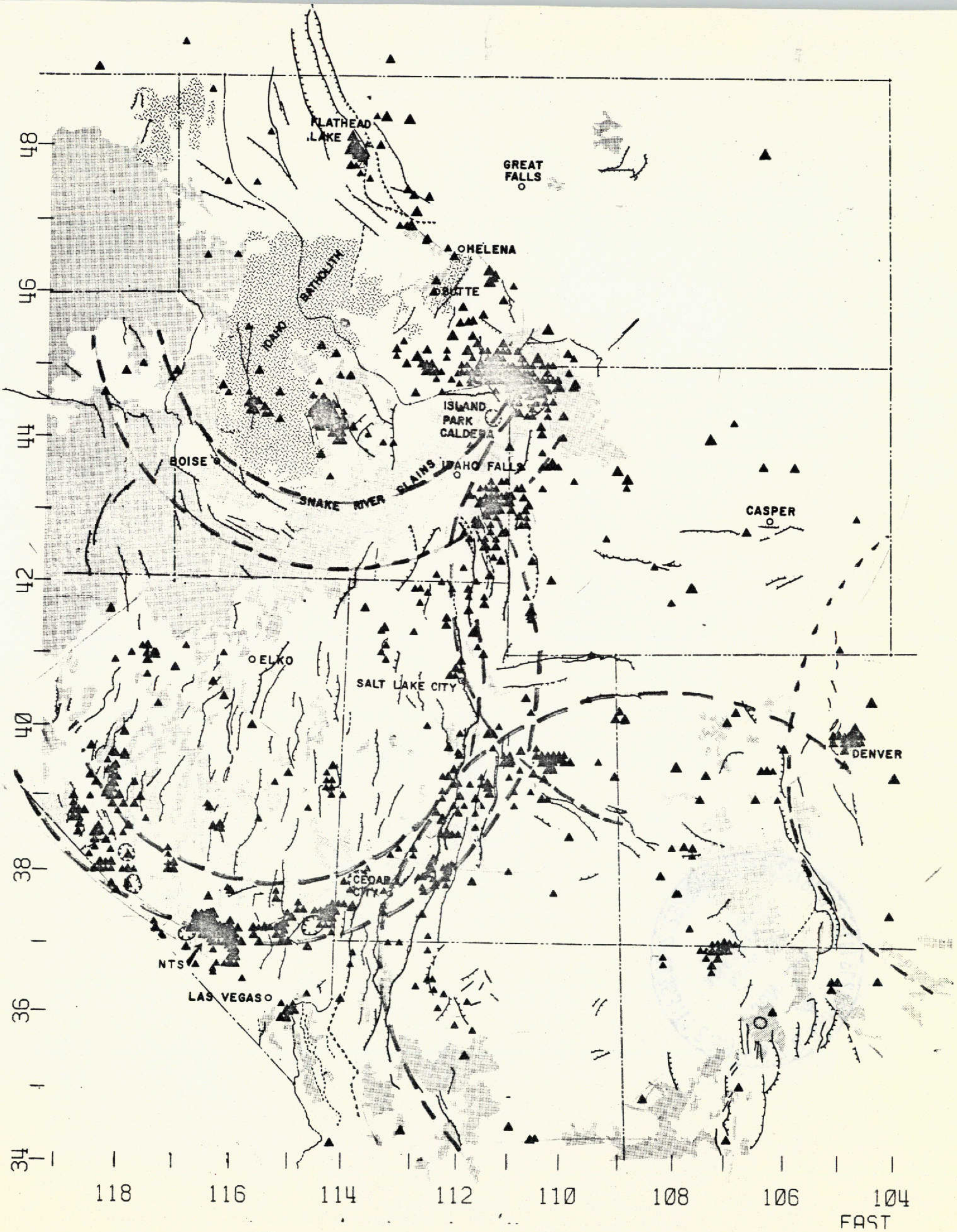
INTERACTION OF TWO MOVING BLOCKS



FROM J. F. Dewey (1972)

Figure 19

MOVEMENT OF TECTONIC PLATES



INTERMOUNTAIN AREA EARTHQUAKES 1961 to 1970 FROM SMITH & SBAR 1973

Figure 20. Possible Arcuate Trends Defined by Seismic Activity.